Bypass to plantar and tarsal arteries: An acceptable approach to limb salvage

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Objective: **This study was undertaken to evaluate our experience with distal arterial bypass to the plantar artery branches and the lateral tarsal artery for ischemic limb salvage.**

Methods: **This was a retrospective analysis of data prospectively entered into our vascular surgery database from January 1990 to January 2003 for all consecutive patients undergoing bypass grafting to the plantar artery branches or the lateral tarsal artery. Median follow-up was 9 months (range, 1-112 months). Demographic data, indications for surgery, outcomes, and patency were recorded, and statistical analysis was performed to assess significance.**

Results: **Ninety-eight bypass procedures to either the medial plantar artery, lateral plantar artery, or lateral tarsal artery were performed in 90 patients. Eighty-one patients (83%) were men. Mean age was 67.5 ± 11.6 years. Indications for operation were tissue loss in 93 patients (95%), rest pain in 3 patients (3%), and failing graft in 2 patients (2%). Eighteen patients (18%) had previously undergone vascular reconstruction, and 5 patients (5%) had undergone previous bypass to the dorsalis pedis artery. Seventy-one grafts (72%) had inflow from the popliteal artery, 25 grafts had inflow from a femoral artery or graft (26%), and 2 grafts had inflow from a tibial artery (2%). Conduits used were greater saphenous vein in 67 patients (69%), arm vein in 20 patients (20%), composite vein in 10 patients (10%), and polytetrafluoroethylene conduit in 1 patient (1%). There were 77 bypasses (79%) to plantar artery branches, and 21 bypasses (21%) to the lateral tarsal artery. Thirty-day mortality was 1% (1 of 98 procedures). Early graft failure within 30 days occurred in 11 patients (11%). In the subset of patients with a previous arterial reconstruction, there were 2 early graft failures within 30 days (11%). Both occurred in patients who had undergone previous bypass to the dorsalis pedis artery. Primary patency, secondary patency, limb salvage, and patient survival were 67%, 70%, 75%, and 91%, respectively, at 12 months, and 41%, 50%, 69%, and 63%, respectively, at 5 years, as determined from Kaplan-Meier survival curves. Greater saphenous vein grafts performed better than all other conduits, with a secondary patency rate of 82% versus 47% at 1 year ($P = .009$).**

Conclusion: **Inframalleolar bypass to plantar artery branches and the lateral tarsal artery, even in patients with a previously failed revascularization, can be undertaken with acceptable patency and limb salvage rates. Early graft failure, however, is higher, whereas patency and limb salvage rates are lower, compared with bypass to the dorsalis pedis artery. The use of saphenous vein as a conduit results in the best patency for plantar or lateral tarsal bypass procedures. (J Vasc Surg 2004; 40:1149-57.)**

Distal vein bypass to the dorsalis pedis artery and paramalleolar posterior tibial artery are now routine procedures for most vascular surgeons. These operations are most commonly performed to treat ischemic foot complications of diabetes mellitus because of the unique pattern of atherosclerosis in these patients. In detailed anatomic studies of amputated limbs from patients with diabetes mellitus, Conrad[1] recognized that even in the presence of extensive tibial and peroneal occlusive disease most limbs had relative sparing of the major foot arteries, especially the dorsalis pedis artery. In our own practice, in which nearly 90% of patients with critical foot ischemia have diabetes, vein bypass to the dorsalis pedis artery has been the singlemost commonly performed bypass procedure, composing nearly 30% of all lower extremity arterial reconstructions.[2]

Occasionally patients have critical foot ischemia at presentation, and when examined it is found that both the dorsalis pedis artery and the paramalleolar posterior tibial artery are occluded, with only branches of these vessels, namely, the tarsal and plantar arteries, remaining patent (Figs 1 and 2). Although the technical feasibility of bypass to pedal branch arteries was demonstrated more than 15 years ago,[3] published series have been small.[3-6] In our experience, we have performed bypasses to the plantar branches and lateral tarsal artery when no other bypass option was feasible and we believed major amputation was the only other treatment option. We undertook this study to review our overall experience with plantar and lateral tarsal bypass with regard to traditional outcome measures of patency, limb salvage, and mortality and to evaluate our results in comparison with our much larger experience with dorsalis pedis bypass.

PATIENTS and METHODS

Data collection. Since 1990, pertinent clinical data for all consecutive patients undergoing lower extremity

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Competition of interest: none.

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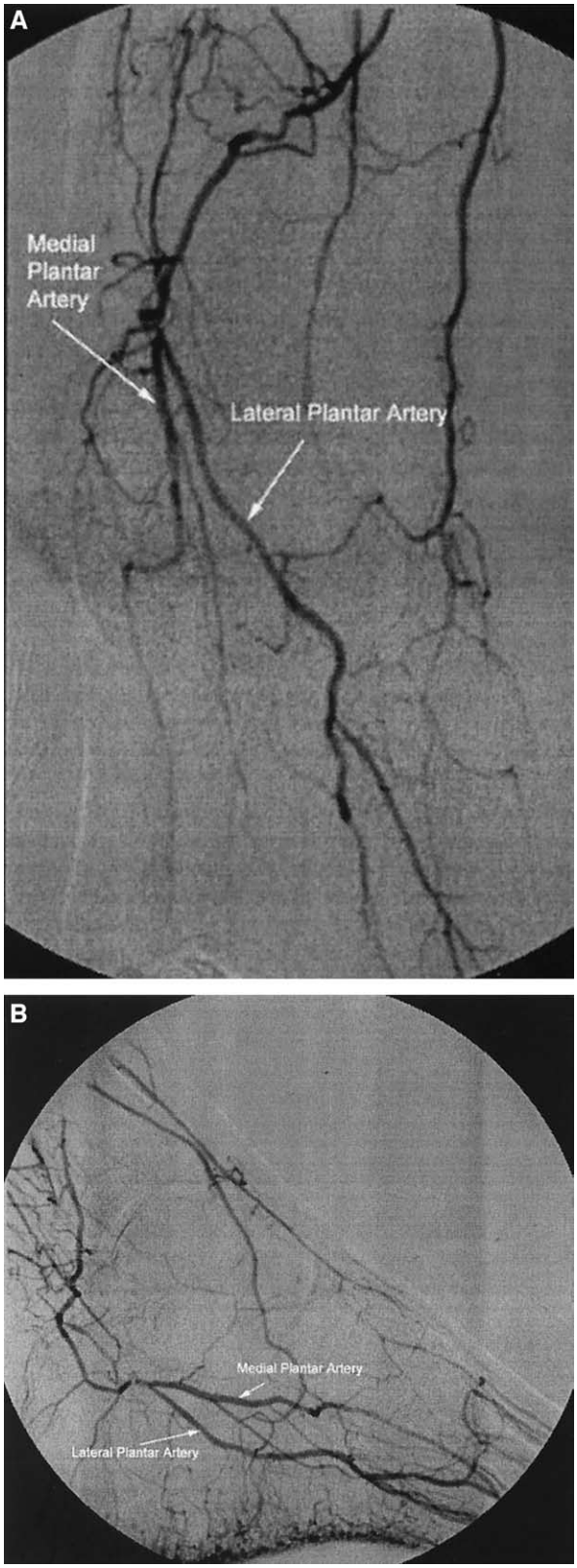

Fig 1. Preoperative anteroposterior **(A)** and lateral **(B)** arteriograms of foot of patient undergoing plantar artery bypass.

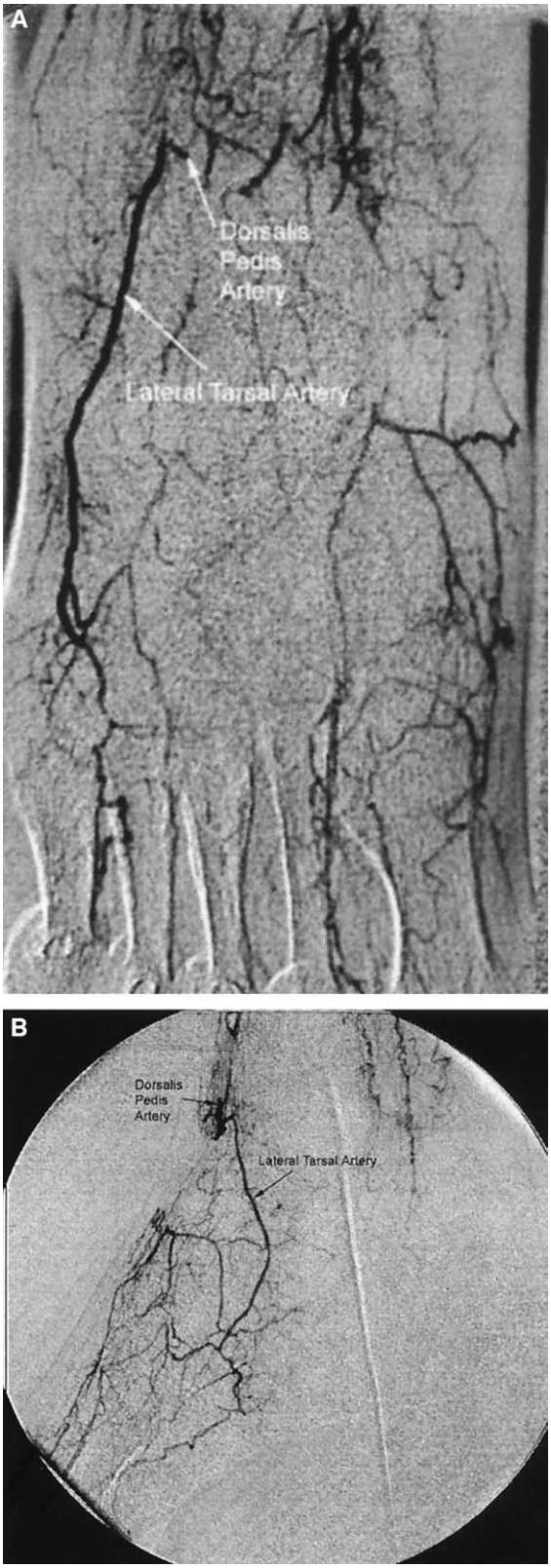

Fig 2. Preoperative anteroposterior **(A)** and lateral **(B)** arteriograms in a patient undergoing lateral tarsal artery bypass. Note stump of occluded dorsalis pedis artery.

arterial reconstruction at Beth Israel Deaconess Medical Center have been entered into a computerized vascular registry. For this study the registry was queried to identify those patients who had a plantar or tarsal artery as an outflow target up to January 2003. Bypasses identified as plantar or tarsal included those that extended only to the plantar bifurcation or the takeoff of the lateral tarsal artery, provided the distal portion of the anastomosis terminated in either of the plantar branches or the lateral tarsal artery, as well as those in which the distal anastomosis was fashioned in its entirety in one of the plantar branches or the lateral tarsal artery. All data were prospectively entered at the time of treatment, and the registry was updated periodically with patient follow-up data. Initial data included demographics, indications for surgery, comorbid conditions, specific operative details, complications, and outcome at discharge from the hospital. Follow-up data included outcomes, graft patency, dates and nature of any graft revision, dates of graft occlusion, and dates of major amputation or death. Retrospective query of the database and chart reviews were performed.

Patient follow-up. Patients were followed up at regular intervals of approximately every 3 months during the first year, every 6 months during the second year, and annually thereafter. Graft patency was determined by the presence of a palpable pulse in the graft by the attending surgeon. Duplex vein graft surveillance was not routinely used during the study. Limb salvage was defined as preservation of enough of the foot to allow ambulation without the need of a prosthetic. This included feet requiring toe, ray, or transmetatarsal amputations, as well as partial or complete resection of the calcaneous. Death during follow-up was determined from the Social Security Death Index.

Statistical analysis. Patient demographic data, indications for surgery, details of the surgical procedure, and follow-up data were analyzed with a commercially available statistics software program (Statview 5.0 software; SAS Institute). All data are presented in accordance with the revised reporting standards of the Joint Council of the Society for Vascular Surgery and the American Association of Vascular Surgery.[7] Graft patency, limb salvage, and patient survival were calculated with the Kaplan-Meier life table method. Comparisons were made with the nonparametric Mantel-Cox log-rank test. Categorical variables were compared with the χ^2 test, and continuous variables with the Student t test. $P < .05$ was considered statistically significant.

Patient selection and surgical management. Only patients with signs and symptoms of limb-threatening ischemia were considered for plantar or lateral tarsal bypass. When present, active infection was treated intravenously with broad-spectrum antibiotic agents, and foot debridement or incision and drainage, as needed, before arterial reconstruction. Infectious diseases and podiatry services were often consulted to assist in patient management. Selection criteria for lateral tarsal or plantar bypass were determined from preoperative intraarterial digital subtraction angiograms. Magnetic resonance angiography, computed tomography angiography, or arterial duplex ultrasound scanning were not used in these patients. Our standard routine for arterial imaging included the abdominal aorta, bilateral pelvis, and the involved extremity to the base of the toes. Magnified anterior and posterior, and lateral projections of the foot vessels were routinely obtained. Occasionally intraarterial vasodilator agents (nitroglycerin 400 μg/mL or papaverine 60-90 mg) were administered during angiography to enhance imaging of the distalmost foot vessels.[8] Plantar or lateral tarsal bypass was chosen only when there was no angiographic evidence of a more proximal outflow target that would enable the foot to heal. In general, the plantar branch or lateral tarsal artery with the largest caliber and least disease was chosen as the outflow target. Our approach to plantar and lateral tarsal bypass is similar to that for dorsalis pedis reconstruction, as described.[9,10] We rely on use of distal inflow sites and short, translocated greater saphenous vein grafts whenever possible. In situ saphenous vein bypass was performed when the bypass originated from the common or superficial femoral artery and the greater saphenous vein was intact. Reversed or nonreversed translocated greater saphenous vein grafts were used for bypasses originating from the popliteal or tibial arteries. The configuration of the saphenous vein was chosen to optimize the match in caliber between the conduit and the inflow and outflow arteries.[10] In the absence of ipsilateral greater saphenous vein, our conduit of choice was arm vein,[11] followed by lesser saphenous vein. Composite grafts composed of different vein segments connected with end-to-end venovenostomies were occasionally used. Angioscopy was routinely used to prepare the vein grafts and to confirm their adequacy as conduits. In the later years of the study preoperative duplex ultrasound vein mapping was frequently used to identify suitable venous conduits.

Exposure of the lateral tarsal artery was accomplished with a longitudinal incision on the dorsum of the foot. The dorsalis pedis artery was exposed first; the takeoff point of the lateral tarsal branch was identified at the level of the navicular bone, and the incision was extended in a slightly lateral direction to expose it completely. The extensor digitorum longus tendons were retracted laterally, and the belly of the extensor hallucis brevis muscle was partially incised to facilitate exposure. The plantar vessels were exposed through an incision posterior to the medial malleolus. The very distal posterior tibial artery would be identified first, and the incision and dissection extended distally, dividing the flexor retinaculum and several crossing veins to expose the plantar bifurcation. In general, the medial plantar branch continues in a straight course from the bifurcation along the medial sole of the foot. Division of the abductor hallucis muscle is usually required to facilitate exposure. The lateral plantar artery takes a slightly more inferior course to the medial plantar artery and is often larger. Usually a segment suitable for bypass can be exposed before it courses laterally across the sole of the foot. Direct exposure of the plantar branches or lateral tarsal artery was

Table 1. Clinical characteristics and surgical indications for patients undergoing plantar/lateral tarsal artery bypass

	Study group	*Lost to follow-up*	P *value*
No. of patients	98	26	
Demographics			
Age	67.5 ± 11.57	66 ± 13.29	.78*
Male gender	81 (83%)	21 (81%)	.82
Diabetes	82 (84%)	22 (85%)	.91
Hypertension	56 (57%)	20 (70%)	.06
CAD	39 (40%)	16 (62%)	.47
Prior MI	32 (33%)	17 (65%)	.85
CHF	15 (15%)	11 (42%)	<.05
Prior CABG	21 (21%)	8 (31%)	.32
Cr >2mg/dL	13 (13%)	4 (15%)	.68
Dialysis	4 (4%)	1 (4%)	.96
Current smoker	17 (17%)	3 (12%)	.47
Indications			
Tissue loss	93 (95%)	23 (88%)	.24
Rest pain	3 (3%)	2 (8%)	.29
Failing graft	2 (2%)	1 (4%)	.59

CAD, Coronary artery disease; *MI,* myocardial infarction; *CHF,* congestive heart failure; *CABG,* coronary artery bypass grafting.
*Student *t* test, all other *P* values generated with χ^2.

not performed. Hemostatic control was obtained with small silicone rubber vessel loops, intra-arterial vessel occluders, or sterile tourniquets,[12] at the discretion of the attending surgeon. Most plantar and lateral tarsal arteries were calcified to some degree, and some were circumferentially calcified.[13] Occasionally the target artery was opened before harvesting the vein, to determine its suitability for bypass. In general, plantar and lateral tarsal arteries were considered suitable if the internal lumen was large enough to permit gentle passage of a 1-mm stainless steel coronary probe or 22-gauge intravenous cannula, some back bleeding was present, and injection of normal saline solution or heparin solution into the artery through a 22-gauge intravenous cannula with a 10-mL syringe did not meet excessive resistance. Some outflow target vessels were smaller than 1 mm. Anastomoses were performed with small-caliber 7-0 or 8-0 polypropylene sutures on fine stainless steel needles with taper-cut points under 2.5× or 3.5× loupe magnification. Completion arteriography was rarely performed; however, all grafts were interrogated with a sterile hand-held continuous wave Doppler probe to assess the presence and adequacy of blood flow.

Foot wounds were closed in a single layer with an absorbable subcuticular suture or a simple interrupted monofilament skin suture. Postoperatively, patients were given aspirin and subcutaneous heparin 5000 U every 8 to 12 hours until discharge. Other antiplatelet agents, such as clopidogrel, and systemic anticoagulation were not routinely used. Some patients were given low-molecular-weight dextran intravenously at a rate of 20 mL/hr for 48 hours after surgery, at the discretion of the attending surgeon. Careful attention was given to minimize the significant foot edema that usually accompanies these bypass procedures and is a major cause of wound complications. This was done with elastic wraps, restricting weight bearing for 2 to 7 days, and encouraging frequent leg elevation in the first few postoperative weeks.

RESULTS

Over 13 years 124 bypasses were performed to the medial plantar, lateral plantar, or lateral tarsal artery. This represented 2.62% of the 4732 lower extremity arterial bypasses performed at our institution during this period. In 98 patients complete follow-up was available, and this group formed the basis of the study. Comparisons, however, were performed to ensure that this study group was representative of the entire population who underwent plantar or lateral tarsal artery bypass. Patient characteristics are shown in Table I, and are compared with the population lost to follow-up. Patients who composed the study sample were comparable to the population lost to follow-up in every category except prevalence of congestive heart failure. Mean age of the study population was 67.5 years in a primarily male population (83%). Eighty-four percent of patients had diabetes mellitus. A substantial number of patients had cardiac comorbid conditions, and renal insufficiency (defined as serum creatinine concentration >2 mg/dL) was present in 13% of patients at operation. Eighteen patients (18%) had undergone previous arterial bypass in the involved extremity. In 5 of these patients the bypass was to the dorsalis pedis artery. All dorsalis pedis bypasses were occluded at the time of plantar or lateral tarsal bypass. Indications for surgery were tissue loss in 95% of patients, rest pain in 3%, and failing graft in 2% (Table I). Table II lists the conduits, inflow and outflow arteries, as compared with the population lost to follow-up. The study group was comparable to the population lost to follow-up in every category except use of a tibial inflow site. Autogenous vein was used in all but 1 patient. The popliteal artery was the inflow site in 72% of procedures. Outflow arteries selected were the lateral tarsal artery in 21.4%, the medial plantar artery in 24.5%, and the lateral plantar artery in 19.4%. In 34.7% the specific plantar branch outflow artery could not

Table II. Conduits, inflow and outflow arteries

	Study group	*Lost to follow-up*	P *value*
No. of procedures	98	26	
Conduit			
Reversed saphenous	29 (30%)	9 (35%)	.62
Nonreversed saphenous	27 (27%)	10 (38%)	.28
Arm vein	20 (20%)	3 (12%)	.30
In situ saphenous	11 (11%)	3 (12%)	.96
Composite vein	10 (10%)	1 (4%)	.09
PTFE	1 (1%)	0 (0%)	.60
Inflow artery			
Below-knee popliteal	58 (59%)	13 (50%)	.40
Above-knee popliteal	13 (13%)	4 (15%)	.78
Common femoral	12 (12%)	4 (15%)	.67
Vein graft	9 (9%)	1 (4%)	.35
Superficial femoral	3 (3%)	0 (0%)	.37
Tibial artery	2 (2%)	4 (15%)	<.05
Prosthetic graft	1 (1%)	0 (0%)	.61
Outflow artery			
Medial plantar	24 (25%)	3 (12%)	.16
Lateral plantar	19 (19%)	2 (8%)	.16
Plantar (unknown medial or lateral)	34 (35%)	14 (54%)	.08
Lateral tarsal	21 (21%)	7 (27%)	.55

PTFE, Polytetrafluoroethylene.

Table III. Perioperative complications

	All patients	*Study group (SG)*	*Lost to follow-up (LTF)*	P *value (SG vs LTF)*
No. of patients	124	98	26	
Early graft failure	12 (9.7%)	11 (11%)	1 (4%)	.26
Symptomatic MI	2 (1.6%)	2 (2%)	0 (0%)	.46
Mortality	2 (1.6%)	1 (1%)	1 (4%)	.31
Congestive heart failure	2 (1.6%)	1 (1%)	1 (4%)	.31
Renal failure	2 (1.6%)	1 (1%)	1 (4%)	.31

MI, Myocardial infarction.

be determined from the database or medical records. In more than half of cases the arteries were moderately to heavily calcified, with 15% requiring use of intraluminal occluders or tourniquets. Median hospital stay was 10.5 days (range, 2-30 days).

Table III lists the perioperative complications as compared with the population lost to follow-up. The 2 groups do not statistically differ with regard to perioperative complications. In the study population, there was 1 death within 30 days of operation. This occurred on postoperative day 3 in a patient with end-stage renal failure who was receiving hemodialysis. Myocardial infarction occurred in 2 patients. Other complications included overt congestive heart failure in 1 patient and renal failure in 1 patient. Early graft failure occurred after 11 operations (11%). Of these, 8 resulted in the need for major amputation, including 6 in which the graft failed and amputation was performed without any attempt to salvage the graft, and 2 others in which an attempt to revise the graft was unsuccessful and amputation was performed within 2 months of the initial bypass procedure. In 3 patients the graft failed immediately; no attempt at graft revision was made, but major amputation was not necessary, and the patients continued to be ambulatory at follow-up intervals of 32 months, 6 months, and 1 month, respectively. One of the early graft failures was in our single patient in the series with a polytetrafluoroethylene conduit . No attempt at graft revision was made in this patient, and below-knee amputation was performed 6 months after bypass. During follow-up, which ranged from 1 to 112 months (median, 9 months), primary patency, secondary patency, and limb salvage rates were 67%, 70%, and 75%, respectively, at 1 year, and 41%, 50%, and 69%, respectively, at 5 years (Fig 3 and Fig 4, *A*). Patient survival was 91% at 1 year and 63% at 5 years (Fig 4, *B*). Greater saphenous vein grafts performed better than all other conduits, with a primary patency rate of 77% versus 47% and a secondary patency rate of 82% versus 47% at 1 year ($P = .0089$). No differences in patency or limb salvage rates were demonstrated between medial plantar, lateral plantar, and lateral tarsal bypass procedures. Univariate analysis identified use of the greater saphenous vein as the only significant variable among 25 clinical factors, which was associated with long-term patency at 1 year after operation (Table IV) .

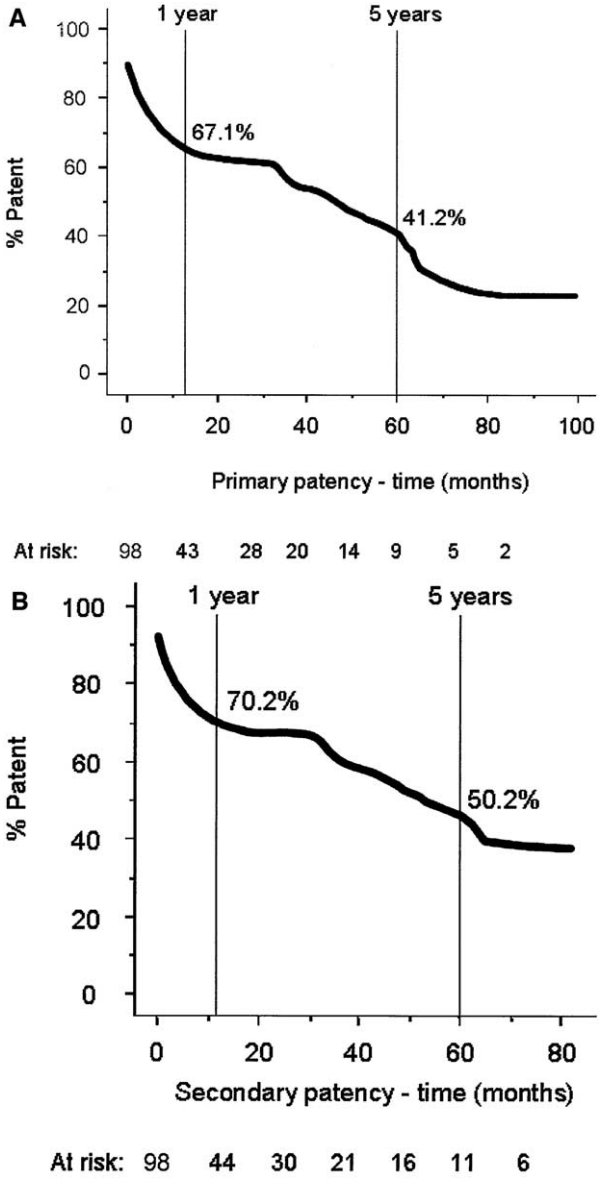

Fig 3. Primary patency **(A)** and secondary patency **(B)** in patients with bypass to medial or lateral plantar artery or lateral tarsal artery. (SE <10% at all time intervals.)

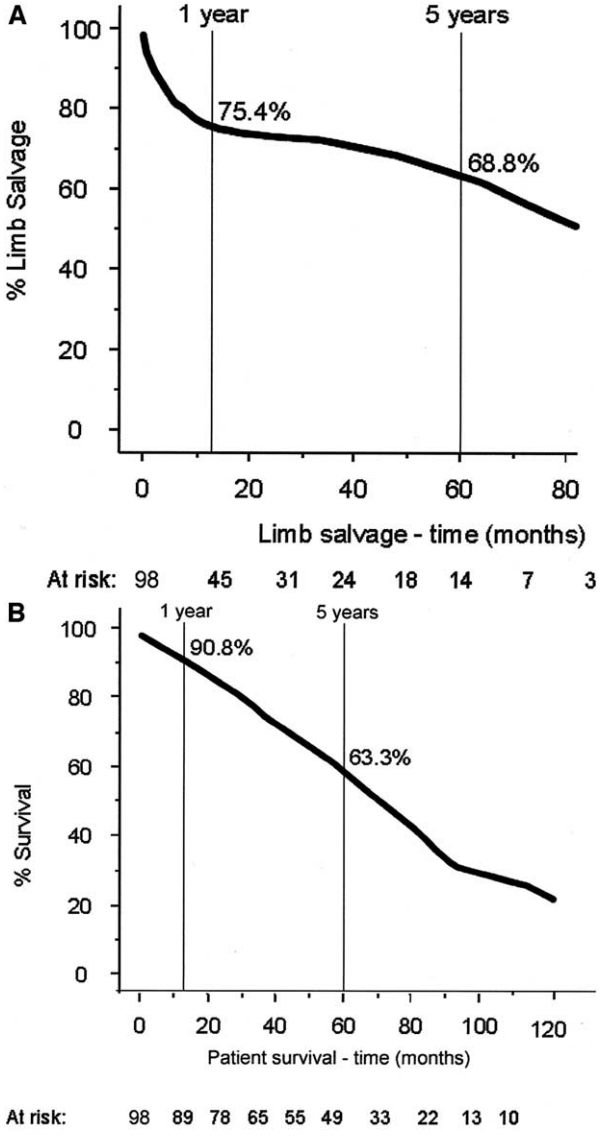

Fig 4. Limb salvage **(A)** and patient survival **(B)** in patients with bypass to medial or lateral plantar artery or lateral tarsal artery. (SE <10% at all time intervals.)

DISCUSSION

Technical improvements in lower extremity arterial reconstructive surgery over the last 3 decades, along with improvements in anesthetic management, have greatly improved the immediate results after lower extremity greater saphenous vein bypass grafting, even to very distal target vessels.[6,9,14-18] Ascer et al[3] first demonstrated the technical feasibility of plantar and tarsal bypass in 1988; however, the number of procedures performed in this and subsequent series[4,5] was small. The current work is a retrospective study of a primarily diabetic population without complete follow-up, and represents the largest published series to date. As the small study population signifies, this is a rarely performed operation, even in an institution accustomed to distal arterial bypass procedures. In this study, as in the others,[3-5] this operation is most commonly performed in patients with diabetes mellitus with extensive infrapopliteal arterial occlusive disease, similar to those requiring dorsalis pedis bypass. However, early graft failure in this study was 11%, more than twice that in our patients undergoing dorsalis pedis bypass[2] (Table V) . Patency and limb salvage rates were also inferior to those obtained in our dorsalis pedis bypass population (Fig 5) . Ascer et al[3] (29%), Roddy et al[6] (26%), and Andros et al[5] (15%) also noted a higher than expected rate of early graft occlusion. Moreover, in the current study only 2 of 11 patients with early graft failure

Table IV. Results of univariate analysis of factors influencing graft patency at 1 year following bypasses to the medial plantar, lateral plantar, or lateral tarsal artery

Clinical factor	P *value*
Gender	.063
Diabetes	.303
Neuropathy	.945
Tobacco	.631
Coronary artery disease	.369
Congestive heart failure	.657
Previous myocardial infarction	.683
Prior coronary artery bypass surgery	1
Prior percutaneous coronary angioplasty	.853
Renal disease	.052
Cr >2	.258
Hemodialysis	.197
Ulcer	.491
Gangrene	.366
Infection	.499
Rest pain	.193
Claudication	.341
Failing graft	.663
Bypass for occluded graft	.276
Revised graft	.146
Greater saphenous vein	.003
Length of stay >10 days	.371
Popliteal inflow	.391
Plantar artery	.263
Tarsal artery	.263
Heel lesion	.425

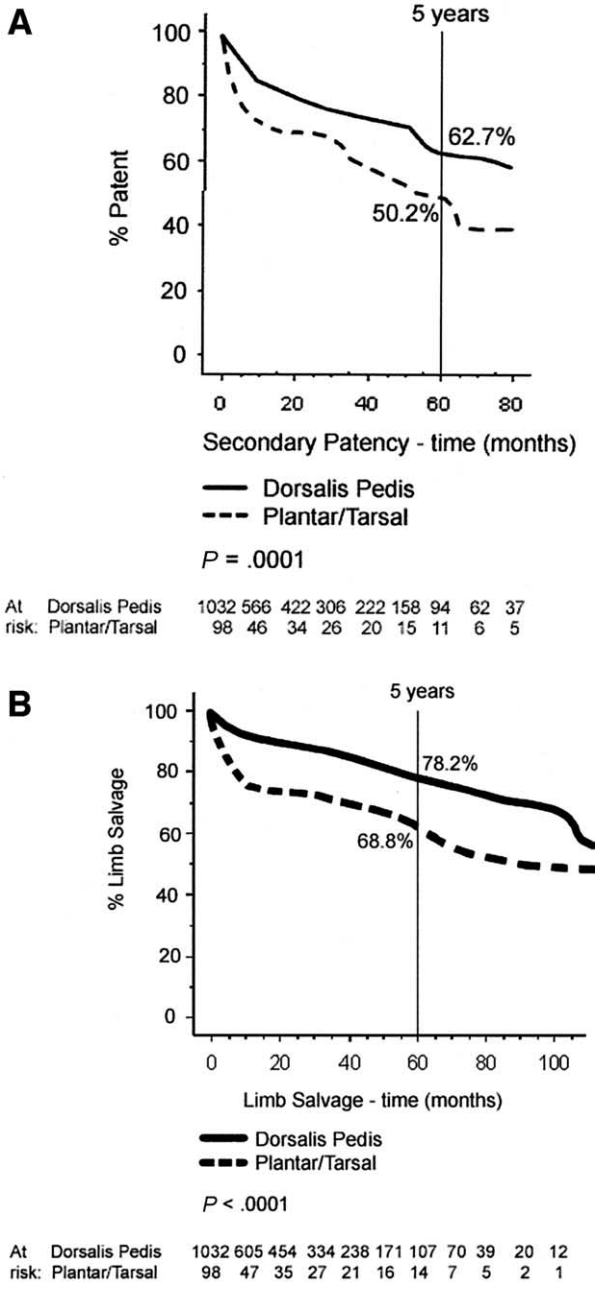

Fig 5. Comparison of secondary patency **(A)** and limb salvage **(B)** between dorsalis pedis bypass and plantar or tarsal bypass patient populations. (SE <10% at all time intervals.)

were immediately returned to the operating room. At repeat exploration a technical cause of failure was not identified in either patient, and it is our impression that failure was most likely due to poor runoff. Thrombectomy and vein patch angioplasty performed in each case was unsuccessful. Ultimately, 8 of 11 patients with early graft failure required amputation, including the 1 patient in whom an ill-conceived attempt was made to revise a failed dorsalis pedis bypass with a prosthetic graft. The infrequency of immediate return to the operating room because of failed grafts underscores our impression that most of these procedures represent a "last ditch" effort at limb salvage and that this probably defines the technical limit of lower extremity arterial reconstruction. Despite the higher than expected early failure rate, outcomes in grafts remaining patent proved quite good. Ascer et al[3] reported a primary patency rate of 67% and a limb salvage rate of 78% (SE, 10%) at 2 years in a series of 24 operations, and Connors et al[4] reported a primary patency rate of 70% and a limb salvage rate of 78% (SE, 10%) at 2 years in another series of 24 pedal branch arterial bypass procedures. In comparison, our 5-year secondary patency and limb salvage rates are 50% and 69%, respectively. The nearly 20% difference between graft patency and limb salvage is notable, and suggests that some procedures may have been performed in patients who may not have had critical ischemia despite a clinical impression to the contrary. It is possible that neuropathy in conjunction with moderate ischemia may have had a role in causing ulcers or tissue loss in some patients. While neuropathy is the antecedent cause of ulcers in such patients, it is the presence of arterial insufficiency that delays or prevents healing (so-called neuro-ischemic ulcers). In our experience, many of these patients will require arterial reconstruction to facilitate wound healing, even though the degree of ischemia is not severe enough in and of itself to result in gangrene or amputation. Consequently, arterial bypasses to treat neuro-ischemic ulcers will result in foot

Table V. Comparison of 5-year results of bypass to plantar or lateral tarsal arteries and dorsalis pedis bypass

	Plantar or lateral tarsal artery (%)	*Dorsalis pedis artery (%)*	P
Early graft failure	11	4.2	.0017*
Primary patency	41	57	.0004
Secondary patency	50	63	.0001
Limb salvage	69	78	<.0001
Patient survival	63	49	.1858

*Comparison with χ^2 test; all other *P* values generated with log-rank test comparing life table curves.

healing while patent but rarely lead to limb loss when they fail, provided the foot has previously healed.

Although the early rate of failure of these procedures is disappointingly high, it is important to recognize that, when successful, pedal branch bypass results in durable limb salvage in most patients. Reconciling the high rate of early graft failure with the high likelihood of limb salvage when grafts remain patent underscores the importance of proper patient selection and begs the question as to whether there are factors that might predict outcome before pedal branch bypass is attempted. At univariate analysis only the use of saphenous vein had an effect on the likelihood of graft patency, although qualitative or quantitative information about runoff was not available, and many arteriograms were no longer available for review, 2 major shortcomings of this study. In general, we have relied on the appearance of the lateral tarsal or plantar arteries on arteriograms, using conventional criteria such as vessel diameter and absence of disease in selecting our outflow target. In this series the plantar branches were more frequently found to be suitable than the lateral tarsal artery as target arteries, although outcomes for the plantar branches compared with the lateral tarsal artery proved similar. No significant difference was noted between medial and lateral plantar arteries, although the medial plantar branch is an end artery with presumably worse runoff than the lateral plantar branch, which connects to the pedal arch. It is notable, however, that a third of patients in the study had bypasses to an unspecified plantar artery.

Consequently, until more specific information is available, the decision of whether to attempt a bypass to a pedal branch artery remains one of surgical judgment. In patients facing imminent amputation with no other bypass option, attempting a bypass to either a plantar branch or the lateral tarsal artery thought to be of acceptable caliber and quality is reasonable, provided vein conduit is available and the foot is salvageable. Patients should be made aware of a higher likelihood of graft failure than with other more proximal arterial reconstructions. If the graft should immediately fail, the surgeon should consider a repeat attempt carefully and with some trepidation. In our experience, these procedures rarely, if ever, restore patency or result in limb salvage, and should be avoided in most patients.

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REFERENCES

1. Conrad MC. Large and small artery occlusion in diabetics and nondiabetics with severe vascular disease. Circulation 1967;36:83-91.
2. Pomposelli FB, Kansal N, Hamdan AD, Belfield A, Sheahan M, Campbell DR, et al. A decade of experience with dorsalis pedis artery bypass: analysis of outcome in more than 1000 cases. J Vasc Surg 2003;37:307-15.
3. Ascer E, Veith FJ, Gupta SK. Bypasses to plantar arteries and other tibial branches: an extended approach to limb salvage. J Vasc Surg 1988;8:434-41.
4. Connors JP, Walsh DB, Nelson PR, Powell RJ, Fillinger MF, Zwolak RM, et al. Pedal branch artery bypass: a viable limb salvage option. J Vasc Surg 2000;32:1071-9.
5. Andros G, Harris RW, Salles-Cunha SX, Dulawa LB, Oblath RW. Lateral plantar artery bypass grafting: defining the limits of foot revascularization. J Vasc Surg 1989;10:511-9; discussion 520-1.
6. Roddy SP, Darling RC III, Chang BB, Kreienberg PB, Paty PS, Lloyd WE, et al. Outcomes with plantar bypass for limb-threatening ischemia. Ann Vasc Surg 2001;15:79-83.
7. Rutherford RB, Baker JD, Ernst C, Johnston KW, Porter JM, Ahn S, et al. Recommended standards for reports dealing with lower extremity ischemia: revised version. J Vasc Surg 1997;26:517-38.
8. Cohen MI, Vogelzang RL. A comparison of techniques for improved visualization of the arteries of the distal lower extremity. AJR Am J Roentgenol 1986;147:1021-4.
9. Pomposelli FB Jr, Marcaccio EJ, Gibbons GW, Campbell DR, Freeman DV, Burgess AM, et al. Dorsalis pedis arterial bypass: durable limb salvage for foot ischemia in patients with diabetes mellitus. J Vasc Surg 1995;21:375-84.
10. Pomposelli FB Jr, Jepsen SJ, Gibbons GW, Campbell DR, Freeman DV, Gaughan BM, et al. A flexible approach to infrapopliteal vein grafts in patients with diabetes mellitus. Arch Surg 1991;126:724-7; discussion 727-9.
11. Faries PL, Arora S, Pomposelli FB Jr, Pulling MC, Smakowski P, Rohan DI, et al. The use of arm vein in lower-extremity revascularization: results of 520 procedures performed in eight years. J Vasc Surg 2000;31:50-9.
12. Wagner WH, Treiman RL, Cossman DV, Cohen JL, Foran RF, Treiman GS, et al. Tourniquet occlusion technique for tibial artery reconstruction. J Vasc Surg 1993;18:637-45; discussion 645-7.
13. Misare BD, Pomposelli FB Jr, Gibbons GW, Campbell DR, Freeman DV, LoGerfo FW. Infrapopliteal bypasses to severely calcified, unclampable outflow arteries: two-year results. J Vasc Surg 1996;24:6-15; discussion 15-6.
14. Andros G, Harris RW, Salles-Cunha SX, Dulawa LB, Oblath RW, Apyan RL. Bypass grafts to the ankle and foot. J Vasc Surg 1988;7:785-94.
15. Darling RC III, Chang BB, Paty PS, Lloyd WE, Leather RP, Shah DM. Choice of peroneal or dorsalis pedis artery bypass for limb salvage. Am J Surg 1995;170:109-12.
16. Gloviczki P, Bower TC, Toomey BJ, Mendonca C, Naessens JM, Schabauer AM, et al. Microscope-aided pedal bypass is an effective and low-risk operation to salvage the ischemic foot. Am J Surg 1994;168:76-84.
17. Quinones-Baldrich WJ, Colburn MD, Ahn SS, Gelabert HA, Moore WS. Very distal bypass for salvage of the severely ischemic extremity. Am J Surg 1993;166:117-23; discussion 123.
18. Shah DM, Darling RC III, Chang BB, Fitzgerald KM, Paty PS, Leather RP. Long-term results of in situ saphenous vein bypass: analysis of 2058 cases. Ann Surg 1995;222:438-46; discussion 446-8.

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DISCUSSION

Dr Daniel B. Walsh (Lebanon, NH). Mr President, Dr Hughes and the Deaconess Group have presented their experience with tarsal and plantar artery bypasses in 90 patients. As you would expect from a group with such extensive lower extremity bypass experience, the results are excellent and match those previously reported.

It is interesting that the authors were initially skeptical about the utility of such distal bypass procedures, because of an expected lack of durability. The results must have been achieved, not only through technical proficiency, but also because of superior patient selection. The nature of their database precludes a detailed analysis of targeted runoff vessels and other important details.

My questions for the authors focus on how they select patients for these pedal branch artery bypasses now.

First, why were there so few women who underwent this procedure? Do they continue to advocate these bypasses with conduits other than the saphenous vein? Would the use of prosthetic conduit now be contraindicated, in their minds?

What are the characteristics of usable versus nonusable target arteries? Is a 1-mm vessel the only selection criteria? Have they any experience with MRA or duplex scanning criteria for selecting these vessels in their more contemporaneous experience? Do they continue to believe the continuous-wave Doppler examination is an adequate or optimal completion study for confirmation of technical adequacy and a predictor of patency?

At the time of graft failure, what did they find? What were the measures that were most often performed and that led to successful continued patency? Do they still advocate immediate return to the operating room in all early graft failures?

Dr Kakra Hughes. We do not know why so few women were treated. Others have noted this finding as well. In the study that was published by your institution, Dr Walsh, more than 90% of the population was men. In our series more than 80% were men, and in a study by Dr Ascher, I believe 77% of patients were men. We don't know why this is, but we do not believe that this finding is due to selection bias for male patients.

As regards conduits, the ipsilateral greater saphenous vein is our conduit of choice. In its absence we prefer to use an arm vein. All of our conduits are prepared with angioscopy to determine their suitability for bypass before proceeding. We discourage the use of prosthetics, and believe their use is ill-advised.

Concerning the characteristics of usable versus nonusable target arteries, we rely on complete intraarterial digital subtraction angiography. We like to see a patent vessel free of significant disease and including the pedal arch. If the tarsal and plantar arteries are both suitable, we choose the one with the larger caliber. We also determine suitability for bypass in the operating room. First, we like to be able to pass at least a 1-mm coronary probe into the distal vessel, although this is not always possible, and we have done bypasses to vessels that are less than 1 mm if we are able to inject heparinized saline solution into the target vessel with a 22-gauge angiography catheter and not meet with too much resistance. Of course, this is subjective. We typically like to see some backbleeding as well. Since many of these determinants are subjective, surgical experience is also very important.

We do not use MRA or duplex scanning for these very distal bypasses, but rely exclusively on angiograms, at least at this point. We do not consider continuous-wave Doppler ultrasound scanning to be a completion study per se. We use it only to ensure that there is in fact flow in the outflow vessel at completion of the operation. We have not found completion angiograpy very helpful. In our experience, most technical failures have been due to problems with the conduit, and we believe that by using angioscopy and ensuring that the conduit is adequate we can be reasonably assured that our technical results will be acceptable. In fact, we looked at this some years ago, comparing angioscopy with completion angiography, though this series was limited to arm vein conduits, and we found that angioscopy was preferable to completion angiography for detecting intraluminal abnormalities (Stonebridge PA, Miller A, Tsoukas A, Brophy CM, Gibbons GW, Freeman DV, et al. Angioscopy of arm vein infrainguinal bypass grafts. Ann Vasc Surg 1991;5:170-5).

Only 2 patients were explored at the time of graft failure. The cause of graft failure in either patient was not due to technical error, and was presumed due to inadequate runoff. The other 9 patients were not explored again, because the surgeon considered the operation to be technically adequate and that this was the limit of his or her technical ability. For this reason, the decision was made at the time of the initial operation not to perform repeat exploration should the graft fail. Most of these patients subsequently required major amputation.

Dr Enrico Ascher (Brooklyn, NY). Having had the opportunity to do this operation about 18 years ago, I certainly have a thousand questions for you, but I will limit them to 2 quick ones.

Have you done any pedal arch bypass operations? I ask this because occasionally we see patients in whom only the pedal arch is intact, and by removing the body of the second metatarsal bone you can certainly approach this artery very easily, do the bypass, and save the patient's leg.

My second question is, what's the difference in your results between the use of the lateral and the medial plantar arteries?

Dr Hughes. Dr Ascher, we are familiar with your technique, but have not yet encountered a situation where we have used it. To the best of our knowledge, results were equivalent for medial and lateral plantar bypasses; however, some records did not specify which plantar branch was used.

Dr Peter Gloviczki (Rochester, Minn). We found in our experience that end-stage renal disease, in addition to composite vein graft, is an independent risk factor for predicting failure. And you didn't mention whether end-stage renal disease was a major player, although I noticed that you didn't find it to be a predictor. So my first question is, do you treat those patients differently?

And my second question is on survival. You didn't mention the dismal survival of this patient population. We found that in those patients who have successful revascularization, survival is as good as 87%, versus those who had failed revascularization and amputation, with survival at 26%. So I'm wondering if you think you can improve survival in your patients with distal artery revascularization?

Dr Hughes. Concerning end-stage renal disease, we did not find that to affect patency in our series; our number of patients with end-stage renal disease, however, was small.

With survival, we found that patient survival in this population was very similar to survival in other patients with very distal bypasses, that is, dorsalis pedis bypasses. We have also observed and have recently published the dismal survival seen in patients undergoing amputations. Although the survival in patients undergoing bypass is better, it is unclear whether the bypass itself can explain this finding.